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ABSTRACTS OF THE LITERATURE EXAMINED BY THE RADIATION SHIELDING INFORMATION CENTER

Space and Accelerator Shielding

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A B S T R A C T S

OF THE LITERATURE EXAMINED BY THE RADIATION SHIELDING INFORMATION CENTER (Space and Accelerator Shielding)

The abstracts included in this loose-leaf binder cover all the space and accelerator shielding documents that are both in the literature store of the Radiation Shielding Information Center and in the initial edition of an RSIC bibliography in these fields. The bibliography, ORNL-RSIC-11, Bibliography, Subject Index, and Author Index of the Literature Examined by the Radiation Shielding Information Center (Space and Accelerator Shielding), November 1965, is being issued along with these first 99 abstracts. Additional abstracts will be issued for inclusion in this loose-leaf binder when the next bibliography is ready for publication.

Although most of the abstracts included here were taken directly from the published documents, some were written by the reviewers for RSIC. These were limited to documents which either did not contain abstracts or contained abstracts that were not sufficiently informative. Only unclassified abstracts are included; all are subject to revision or replacement. At the lefthand margin next to each abstract is an RSIC accession number for the document itself.

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Indexes to the abstracts both by subject matter and by author can be found in the bibliography.

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- OS. Millard L. Wohl, A Monte Carlo Calculation of the Nuclear Collision Density of Primary Galactic Protons in a Slab of Aluminum, NASA TN D-2122 (March 1964). Availability: \$0.50, CFSTI.

A Monte Carlo code was written for the IBM 7090 computer. The code considers protons in the primary galactic energy range (0.1 to 10 Bev) impinging at angles of 0° , 30° , 45° , and 60° , as well as isotropically, on an infinite slab of aluminum 55 centimeters thick. The average proton nuclear collision density in each of six laminar regions of the slab is computed.

In addition, the energy distribution of evaporation neutrons from the resulting excited nuclei is computed, and the statistical model assumed to be valid. The proton collision density may be used as the spatial source density distribution for calculations of the transport of the secondary neutrons.

- 1S. Martin J. Berger, "Monte Carlo Calculation of the Penetration and Diffusion of Fast Charged Particles," Methods in Computational Physics, 1, 135-215 (1963).

The simulation, by random sampling, of multiple Coulomb scattering for fast charged particles is discussed. The solutions for several typical problems are given.

- 2S. B. W. Mar, "Electron Shielding for Space Vehicles," Trans. Am. Nucl. Soc., 7, 322-323 (November 1964).

An analytic fit to Monte Carlo electron transmission data is given.

- 3S. Richard H. Levy and G. Sargent Janes, "Plasma Radiation Shielding," AIAA Journal, 2(10), 1835-1838 (October 1964).

A method of shielding against space radiation which combines magnetic and electrostatic shielding is proposed.

- 4S. S. Biswas, "The Composition of Solar Particle Radiation," International Conference on Cosmic Rays, I, 43-60 (1964).

The present state of knowledge of the composition of solar particle radiation is summarized.

- 5S. Roger Wallace, "Shielding and Activation Considerations for a Meson Factory," Nucl. Instr. Methods, 18/19, 405-416 (1962).

The shielding and activations of a meson factory are estimated by computing the emission spectra of the neutrons produced, and using these spectra to estimate the necessary shielding and the probable activation of the accelerator caused by the captured neutrons. The technique used in making these estimates is explained. It is assumed that a meson factory has an internal circulating beam current of 100 μ A of 450-, 600-, or 850-MeV protons. This beam will be assumed to hit an aluminum target of 100 g/cm².

- 6S. R. M. Sternheimer, "Range-Energy Relations for Protons in Be, C, Al, Cu, Pb, and Air," Phys. Rev., 115(1), 137-142 (July 1959).

Range-energy relations for protons have been obtained for six substances (Be, C, Al, Cu, Pb, and air). The calculations of the energy loss dE/dx include the shell corrections at low energies and the density effect which becomes important in the high-energy region. The present results can also be used to determine the range of μ mesons up to ~ 10 Bev. Besides the calculated values of the ranges, tables of the ionization loss dE/dx are also presented.

- 7S. D. L. Dye and J. C. Noyes, "Biological Shielding for Radiation Belt Particles," J. Astronaut. Sci., 7(3), 64-70 (Fall 1960).

Calculations are made, for the particle spectra in the most intense regions of the radiation belts, of the attenuation of the particle flux by shielding on a space vehicle, and of the biological dose rate due to the flux which has penetrated the shielding. Both protons and electrons are considered in the inner belt, but only electrons in the outer belt. Secondary particles and bremsstrahlung produced by these particles on interacting with a shield are also considered. It is shown that, despite the much higher electron fluxes, the protons are of much greater biological significance.

- 8S. S. P. Shen, "Nuclear Problems in Radiation Shielding in Space," Astronaut. Acta, IX/FASC.4, 212-274 (1963).

The fundamental physical problems encountered in the shielding and depth dosimetry of energetic particles in space are reviewed and discussed. This is done by examining the various phenomena accompanying the passage of a charged strongly-interacting particle in a condensed medium. The electromagnetic (i.e., atomic) interactions and their aggregate effect, being comparatively well understood, are only briefly recalled. The high-energy nuclear interactions and their outcomes are discussed in greater detail, together with their significance for shielding and dosimetry. The roles of the interaction secondaries and the development in the absorbing medium of a chain of nuclear interactions (nuclear cascade) are discussed at length. This is followed by a review of accelerator experiments of relevance to nuclear-cascade studies, employing protons from 0.1 to 25 GeV. The theory of the nuclear cascade is then briefly outlined, as well as current efforts to calculate the cascade. The article concludes with a recapitulation of the astronautical and astrophysical applications of nuclear-cascade studies and of the present state of shielding physics. Items of interest to the nascent field of high-energy depth dosimetry are recapitulated in an appendix. Other appendices remark on the diffusion of heavy cosmic rays, on the effects of very-high-energy cosmic rays, and on induced radioactivities.

- 9S. Trutz Foelsche, Current Estimates of Radiation Doses in Space, NASA TN D-1267 (July 1962). Availability: \$1.25, CFSTI.

A gross survey of data on energetic radiation in the environment of the earth is presented. This survey embraces the Van Allen belt radiations, galactic cosmic radiations, and solar cosmic radiations associated with solar flares. In the light of the current data the radiation problem is analyzed in terms of shielding requirements to keep exposure down to "tolerable" limits in manned space flights. The estimates are preliminary, especially in the cases of chance encounter with flare protons, since the available data are incomplete and only allow calculations of upper and lower limits of physical doses. Also the contribution of certain primaries and secondaries to the biological effect is not finally known.

- 10S. Clayton D. Zerby, Material Requirements for Shielding Against Space Radiations, ORNL-TM-552 (May 21, 1963). Availability: \$3.60 (fs), \$1.31 (mf), CFSTI.

A brief but general discussion of the material requirements for shielding against space radiations is presented. Emphasis is placed on describing the salient features of the space radiation attenuation problem in order to deduce the materials that will most likely produce minimum-weight shields. The shielding characteristics of the materials are described as a function of atomic weights and no specific materials are referred to. In general it is found that the light atomic weight elements give the minimum-weight shields.

- 11S. H. I. West, Jr., L. G. Mann, and S. D. Bloom, Some Electron Spectra in the Radiation Belts in the Fall of 1962, UCRL 7659 (April 13, 1964). Availability: \$1.00, CFSTI.

A five-channel magnetic electron spectrometer was flown on the U. S. Air Force satellite 1962 β k during the Fall of 1962. Energy channels were provided at 325, 955, 1630, 2400, and 3250 keV. Background was determined from two background channels and from the pitch-angle distributions of the data.

Representative spectra were obtained for most of the regions of the geomagnetosphere. The electron spectra were found to be strongly L-dependent, but usually only slightly B-dependent. Low L-shell data showed a high-energy spectrum characteristic of the injection of fission debris electrons from the Starfish nuclear explosion. The spectra softened with increasing L. Peak fluxes at $L \sim 1.3$ were about 4×10^8 electrons/cm²-sec for electrons > 300 keV. In December an inventory of electrons > 300 keV for $L < 1.7$ was $4.4 \pm 1.3 \times 10^{24}$.

The peak of the outer belt at $L \sim 4.5$ showed spectra which can be presented very approximately as an exponential falling off a factor e^{-1} in about 600 keV. At $\lambda \sim 50^\circ$ a typical quiet-period flux for electrons > 300 keV was 7.7×10^6 , electrons/cm²sec.

Transiently trapped electrons were observed. These are electrons which will be precipitated when they drift eastward into the region of the magnetic anomaly in the earth's field. The pitch-angle distributions of these electrons are usually very strongly energy dependent, narrowing with increasing energy. The region $L = 1.6$ to 1.8 also shows marked energy dependence of the pitch-angle distributions. In such regions the spectrum is dependent upon pitch angle.

- 12S. R. K. Wilson, R. A. Miller and R. L. Kloster, A Study of Space Radiation Problems for Manned Vehicles, FZK-144 (June 8, 1962). Availability: \$13.50 (ph), \$5.95 (mf), CFSTI.

The resolution of the problem of protecting space vehicle crews from charged particles of either solar-flare or trapped-radiation origin will probably depend upon some sort of shielding. The basic problem is concerned with determining quantitatively the attenuation requirement of the incident radiation and selecting an appropriate material to provide this shielding. The discussion given includes the hazards of space radiation, the methods of dose calculation, the development of a proton penetration procedure, a summary of cross section data, and the results of shielding calculations—with particular emphasis on contributions to the dose from secondary radiation.

- 13S. Walter H. Barkas and Martin J. Berger, Tables of Energy Losses and Ranges of Heavy Charged Particles, NASA SP-3013 (1964). Availability: \$4.00 (fs), \$1.00 (mf), CFSTI.

Two-variable proton stopping power and range tables are given as functions of the particle energy τ and of the mean excitation energy I_{adj} of the medium for 160 values of τ between 1 and 5000 Mev, and for 36 values of I_{adj} . These tables can be applied to any medium with specified mean excitation energy. By simple scaling, they can also be applied to other heavy particles with mass and charge different from that of the proton. The tabulated values below 8 Mev are based on experimental stopping-power and range data as summarized by a 9-parameter least-squares range formula. Above 8 Mev they are based on the Bethe stopping power theory, except for the shell corrections which are calculated by an empirical formula in the variables τ and I_{adj} derived from the analysis of experimental data. The two-variable tables do not include the density effect correction which begins to be appreciable when the kinetic energy of the particle is approximately equal to the rest mass. Stopping power and range tables which include the density effect correction are given for protons, kaons, pions, and muons, for 36 elements and compounds.

- 14S. Martin J. Berger and Stephen M. Seltzer, Tables of Energy Losses and Ranges of Electrons and Positrons, NASA SP-3012 (1964).
Availability: \$4.00 (fs), \$1.00 (mf), CFSTI.

Tables are presented for approximately forty materials, and eighty energies between 10 kev and 1000 Mev, which contain the following information: mean energy loss of electrons by collisions with atomic electrons and by bremsstrahlung, the mean range, and the radiation yield (conversion of electron kinetic energy into bremsstrahlung energy). Auxiliary tables contain information about restricted collision losses in water, critical energies (at which the collision and bremsstrahlung losses are equal), and electron/positron differences in regard to energy loss and range. Some comparisons are made between calculated and experimental values of the mean energy loss.

- 15S. H. I. West, Jr., L. G. Mann and S. D. Bloom, Spectra and Fluxes of Electrons Trapped in the Earth's Magnetic Field Following Recent High Altitude Nuclear Bursts, UCRL 7309 (Rev.I), (April 10, 1963). Availability: \$0.75 (fs), CFSTI.

Electron spectral measurements were made on an Air Force satellite launched in later October 1962. Measurements were made in the following energy channel: 325, 955, 1630, 2400, and 3250 keV. We observed a high altitude event ($L = 1.8-3$) on October 28 and obtained data for several days afterwards. The spectra do not resemble a fission spectrum. Electron distributions observed at $L \sim 1.8$ to 2.2 near the equator were peaked $\sim 3.5^\circ$ to the field direction. Electrons from Starfish were observed, and do resemble an equilibrium fission spectrum. Angular distributions $\sim 14^\circ$ from the geomagnetic equator were $\sim 20^\circ$ wide (full width at half maximum). Isotropic fluxes in this region were $\sim 10^8$ electrons/cm²/sec at the end of October. Measurements December 8 near the geomagnetic equator gave isotropic fluxes of $\sim 3 \times 10^8$ electrons/cm²/sec with distributions $\sim 50^\circ$ wide.

- 16S. C. J. Tsao, R. B. Curtis, B. K. Harrison, and G. K. O'Neill, "Monte Carlo Calculations of the Shielding of the Princeton-Pennsylvania 3-BeV Proton Synchrotron," Bull. Am. Phys. Soc., 3, 169 (1958).

The Princeton Pennsylvania 3 BeV proton synchrotron is designed to have a relatively intense beam and its shielding is therefore an important problem. Although approximate calculations have been made in the preliminary designs, it is felt that a more careful one should be tried. This is also motivated by the fact that the cost of the shield is very high. A Monte Carlo type of calculation has previously been made in which the geometrical and physical situations treated are comparatively simple. The present work is an attempt at a more complete calculation. In particular, the actual geometry of the shielding is used. The accuracy of the final results naturally cannot exceed that imposed by the uncertainties in the knowledge of the physical processes involved, but it can be improved later when more reliable data are available. This work is at least a first approach to such calculations.

- 17S. E. A. Edelsack, W. E. Kreger, W. Mallet, N. E. Scofield, Experimental Investigation of Thick Target Bremsstrahlung Radiation from Electrons of 1.00, 1.50, and 2.00 MeV, USNRDL-tr-237 (May 27, 1958). Availability: U.S. Naval Radiological Defense Laboratory, San Francisco, California as AD 201171.

Measurements have been made of the 0° bremsstrahlung spectrum emerging from thick targets of polystyrene, aluminum, copper, silver, and gold bombarded by monoenergetic electrons of 1.0 Mev, 1.5 Mev and 2.0 Mev. The measurements were made using a 4 inch diameter by 4 inch long NaI(Tl) scintillation detector unit with a lead shield and collimator. The pulse height spectra were recorded in a twenty-channel pulse height analyzer and were converted to photon spectra using an experimentally determined response matrix for the scintillation detector. Directions and errors are discussed and the results are plotted as families of curves of number of photons per Mev per microampere per steradian at zero degrees versus photon energy. Comparisons are made with some very elementary semiempirical predictions of thick target bremsstrahlung spectrum shapes.

- 18S. James K. DePagter and Mircea Fotino, Shielding Measurements on a 4-GeV Photon Beam, CEAL-1004 (June 6, 1963). Availability: \$2.60 (fs), \$1.01 (mf), CFSTI.

Results are given for the angular and longitudinal distributions of radiation intensities transmitted through shielding walls in directions parallel and perpendicular to a collimated 4-GeV photon beam. The main exponential attenuation coefficients obtained for ilmenite-loaded concrete ($\rho = 4.0$) are: (i) transverse (at $\theta = 70^\circ$) - nucleonic shower: $\lambda = 2.1/\text{ft}$; (ii) longitudinal ($0 < \theta < 10^\circ$) - nucleonic shower ($2 < t < 6 \text{ ft}$) $\lambda_n = 1.5/\text{ft}$; muons ($t > 8 \text{ ft}$) $\lambda_\mu = 0.35/\text{ft}$. Soft shower penetration: 6 ft. An attempt is made to analyze the nature of the transmitted radiation.

- 19S. S. Z. Belenky, Calculation of Distribution Function Moments of Cascade Particles, AEC-tr-6059 (October 1963). Availability: \$1.10 (fs), \$0.80 (mf) JCL or CFSTI.

A recurrent formula is derived which permits to calculate all distribution function moments of cascade particles in series. The distribution function is calculated for some extreme cases by the moments method.

- 20S. Samuel Kao and Gustav-Adolf Voss, Effectiveness of Ilmenite-Loaded Concrete in Attenuating Neutron Radiation Produced by a 5-Bev Photon Beam, CEAL-1007 (December 20, 1963). Availability: \$1.10 (fs), \$0.80 (mf), CFSTI.

The neutron radiation was produced by directing a 5-Bev bremsstrahlung beam at a heavy copper quantameter serving as target. The transverse (90°) neutron flux was attenuated by a variable-thickness wall of ilmenite-loaded concrete having a density of 4.0 g/cm^3 , and the biological dose, in rems, behind the wall was determined with the aid of a Texas Nuclear Corporation Model 9120 neutron dosimeter. The half-value thickness of the ilmenite-loaded concrete was found to be 3.2 inches when the wall thickness was 1 to 2 ft. and 6.4 inches when the thickness was 2 to 3 ft.

- 21S. J. Ranft, Monte Carlo Calculation of the Nucleon-Meson Cascade in Shielding Materials Initiated by Incoming Proton Beams with Energies Between 10 and 1000 GeV, CERN-64-47 (November 18, 1964). Availability: European Organization for Nuclear Research, Proton Synchrotron Machine Division, Geneva, Switzerland.

Monte Carlo calculations of the nucleon-meson cascade in iron are carried out for incoming proton beams in the energy range 10 to 1000 GeV. The results of the calculation for energies 10 and 20 GeV are compared with the corresponding experimental results and show reasonably good agreement.

- 22S. W. Peter Trower, Beverly Hill Willis, and Charles W. Stableford, High Energy Particle Data - Volume I, Kinematics of Particles as a Function of Kinetic Energy, UCRL-2426 (Vol. I), (July 1, 1963). Availability: \$0.50, CFSTI.

The data in this report pertains to the kinematics and dynamics of elementary particle reactions leading to two particle final states. The reacting particles range from electrons to alpha particles with energies from 1 KeV to 100 GeV depending on the particle. The bulk of the report consists of a series of graphs containing some of the quantities needed for the relativistic calculation of the energy and momentum of the final products. Most of the remainder of the report contains descriptions of simple calculational and graphical techniques that can be used in the relativistic kinematics calculations.

- 23S. M. M. Komochkov, The Fundamental Aspects of Shielding from Radiation of Accelerators of Protons, Deuterons and Alpha Particles, UCRL-Trans.-1062L (April 1964). Availability: \$3.00 (fs), CFSTI.

A critical survey of works connected with accelerator shielding is given. Some experimental and calculational data, not previously published, is included.

- 24S. Conference on Shielding of High-Energy Accelerators held at New York, April 11 to 13, 1957, TID-7545 (December 6, 1957). Availability: \$34 (ph), \$9.90 (mf), CFSTI.

No abstract needed.

- 25S. Hermann J. Schaefer, Dosimetric Evaluation of the Alpha Flux in Solar Particle Beams, NSAM-912 (November 1964). Availability: \$2.00 (fs), \$0.50 (mf) CFSTI as AD-611323.

The dose behind various shield thicknesses from the alpha particle component of typical solar flares is calculated.

- 26S. C. D. Zerby and H. S. Moran, A Monte Carlo Calculation of the Three-Dimensional Development of High-Energy Electron-Photon Cascade Showers, ORNL-TM-422 (December 3, 1962). Availability: \$2.60 (fs), \$0.98 (mf), CFSTI.

A description is given of a general-purpose Monte Carlo program for study of the three-dimensional development of high-energy electron-photon cascade showers in a homogeneous medium. The results of several study calculations are compared with previous analytic work to demonstrate the accuracy of the calculation. Another comparison with an experiment which measured the spatial distribution of the energy deposition in tin by 185-Mev electron-initiated showers shows a discrepancy between calculation and experiment.

- 27S. C. D. Zerby and H. S. Moran, A Collimator Study for a 20-Gev Electron Beam, ORNL-TM-524 (March 25, 1963). Availability: \$1.60 (fs), \$0.80 (mf), CFSTI.

A study was made of the effectiveness of a 162.5076-cm-thick (18 radiation lengths) aluminum collimator in a 20-Gev electron beam. The collimator was cylindrical with an inside radius of 0.3175 cm. Numerical results are presented of the energy absorbed and penetrating for the case of narrow beams incident at various distances from the lip of the hole. The energy penetrating and the distribution of the energy deposition in the collimator is given for a uniform beam with an outside radius of 1.1303 cm.

- 28S. C. D. Zerby and H. S. Moran, A Collimator Study for a 5-Gev Electron Beam, ORNL-TM-423 (December 7, 1962). Availability: \$2.60 (fs), \$0.89 (mf), CFSTI.

A calculation to determine the effectiveness of collimators in a high-energy electron beam is described. Numerical results for a 5-Gev electron beam incident on a 135-42-cm-thick aluminum collimator with an inside radius of 0.85 cm are reported.

- 29S. S. J. Lindenbaum, "Collisions of ≤ 1 Bev Particles (Excluding Electrons and Photons) with Nuclei," Ann. Rev. Nucl. Sci., 7, 317 (1957).

A review of the available information on the interaction of nucleons and pions with nuclei is given.

- 30S. R. G. Alsmiller, Jr., A Note on Importance Functions for the Shielding of Manned Space Vehicles, ORNL-3583 (March 1964). Availability: \$0.75, CFSTI.

The tissue dose calculations of Kinney and Zerby have been used to calculate several importance functions which are of interest in the shielding of manned space vehicles. The functions considered are concerned with the dose from primary and secondary particles in the tissue which arise from a solar-flare proton spectrum that has penetrated an aluminum shield. The secondary particles which are produced in the aluminum are not considered.

- 31S. R. G. Alsmiller, Jr., A Solution to the Nucleon-Meson Cascade Equations Under Very Special Conditions, ORNL-3570 (March 1964). Availability: \$0.75, CFSTI.

The equations which describe a one-dimensional nucleon-meson cascade are solved under the following assumptions:

1. The secondary-particle production kernels are taken to be of the special form

$$F_{ij}(E', E) = \alpha_i \gamma_j e^{\nu(E' - E)} \text{ for all } i, j$$

$$\alpha_i, \gamma_j, \nu = \text{const.};$$

2. pion decay is neglected;
3. pion and nucleon nonelastic cross sections are taken to be constant;
4. The stopping powers of all charged particles are equal to the same nonzero constant.

- 32S. H. W. Bertini, Description of Printed Output from Intranuclear Cascade Calculation, ORNL-3433 (May 14, 1963). Availability: \$2.25, CFSTI.

This report gives a detailed description of the printed output sheets from the intranuclear cascade calculation described in ORNL-3383.

- 33S. H. W. Bertini, A Literature Survey of Nonelastic Reactions for Nucleons and Pions Incident on Complex Nuclei at Energies between 20 MeV and 33 GeV, ORNL-3455 (August 9, 1963). Availability: \$2.50, CFSTI.

A literature survey has been made of experimental data on non-elastic reactions of protons, neutrons, π^+ , and π^- with complex nuclei for incident energies of 20 MeV to 33 GeV. Only those reactions in which nucleons and π -mesons are emitted were considered. The survey was in general confined to publications for which abstracts appear in the journal Physics Abstracts. For pions the period covered is January 1955 to November 1962 and for nucleons it is for January 1957 to November 1962.

- 34S. R. G. Alsmiller, Jr. and F. S. Alsmiller, A Perturbation Method for Solving the Angle Dependent Nucleon-Meson Cascade Equations, ORNL-3467 (July 16, 1963). Availability: \$0.75, CFSTI.

A method is described for obtaining an approximate solution to the equations describing a nucleon-meson cascade by using the angular dependence of the secondary particle production kernels as a perturbation. The usefulness of the method lies in the fact that in a slab geometry the equations which must be solved numerically are essentially the same as those which are used in the straight-ahead approximation and have been solved previously.

- 35S. R. G. Alsmiller, Jr., and J. E. Murphy, Space Vehicle Shielding Studies (Part III): The Attenuation of a Particular Solar Flare by an Aluminum Shield, ORNL-3549 (February 6, 1964). Availability: \$0.50, CFSTI.

Using the straight-ahead approximation, nucleon-meson cascade calculations have been carried out for a particular solar-flare proton spectrum incident on a shield. The shielding material has approximately the properties of aluminum. Both spherical-shell and slab geometries are considered.

- 36S. R. G. Alsmiller, Jr. and J. E. Murphy, Space Vehicle Shielding Studies (Part II): The Attenuation of Solar Flares by Aluminum Shields, ORNL-3520 (January 10, 1964). Availability: \$0.50, CFSTI.

Using the straight-ahead approximation, nucleon-meson cascade calculations have been carried out for several solar-flare proton spectra incident on a shield. The shield material has approximately the properties of aluminum. Both spherical-shell and slab geometries are considered.

- 37S. R. W. Peelle, Statistical Fluctuations in the Output of an Intranuclear Cascade Monte Carlo Computation, ORNL-TM-771 (January 17, 1964). Availability: \$1.60 (fs), \$0.80 (mf), CFSTI.

An effort has been made to estimate the magnitude of the statistical fluctuations in the differential secondary-nucleon cross-section output by the Bertini intranuclear cascade computation and to compare these estimates to the scatter observed between successive Monte Carlo outputs. Poisson statistics are found to be adequate to explain the fluctuations in the number of outgoing particles estimated for small energy and angle ranges. A chi-square test with one degree of freedom was performed for each energy and angle bin, and both the distribution of these values and the combined chi-square test confirm the reasonableness of the estimated variances. To explain the fluctuations in the output of the associated nucleon evaporation program, it is necessary to employ variance estimates based on a binomial approximation. A complete statistical analysis of the problem is not performed.

- 38S. G. T. Jacobs, Editor, Proceedings of Conference on Radiation Problems in Manned Space Flight, June 1960, Washington, D. C., NASA TN-D-588 (December 1960). Availability: \$2.25 (fs), CFSTI.

No abstract needed.

- 39S. H. Wade Patterson, The Effect of Shielding on Radiation Produced by the 730-Mev Synchrocyclotron and the 6.3-GeV Proton Synchrotron at the Lawrence Radiation Laboratory, UCRL-10061 (January 25, 1962). Availability: Lawrence Radiation Laboratory, Berkeley, California.

Calculation of shielding thickness should be compared with experimental data obtained with various detectors. Such data are presented for two accelerators. For the relatively well-shielded synchrocyclotron, emphasis is given to data which show how neutrons are attenuated in the primary shield and the composition of the remaining radiation field in areas close to the accelerator. For the Bevatron, which lacks a complete roof shield, data are given which show the distance dependence and the attenuation in concrete of neutrons that leave the machine in an upward direction.

- 40S. Alan R. Smith, Joseph B. McCaslin, and Michael A. Pick, Radiation Field Inside a Thick Concrete Shield for 6.2-BeV Incident Protons, UCRL-11331 (September 18, 1964). Availability: \$2.00 (fs), \$0.50 (mn), CFSTI.

We describe an investigation of some characteristics of the radiation field inside a massive shield of ordinary concrete when such a structure is bombarded by a sharply focussed beam of 6.3-BeV protons. For our purpose, the external proton beam from the Berkeley Bevatron is directed onto one face of the shield array. This array permits study of the radiation field to depths of 24 ft along the beam axis, and laterally to distances of 10 ft off-axis.

Attenuation measurements obtained during the experiment are presented here. Complete sets of lateral activity profiles were obtained with gold foils (thermal-neutron flux), aluminum discs (flux greater than 7 MeV), and carbon scintillators (flux greater than 20 MeV). Several transformations of the data are shown in an effort to clarify properties of the radiation field as viewed by these three detectors.

Such information should be of immediate value to shield design at particle accelerators in the multi-BeV energy range; therefore we present the attenuation measurements now, and do not delay until data processing and analysis from other aspects of the experiment are complete. These aspects include measurement of fast-neutron flux, fast-neutron spectra, and induced activation of several important accelerator construction materials; the results will be reported as they become available.

- 41S. C. Passow, Solved and Unsolved Problems in Shielding Calculations for Accelerators with Energies below 150 GeV (1962). Availability: Deutsches Elektronen-Synchrotron, Hamburg, Germany.

A review of shielding calculations for high energy accelerators is given.

- 42S. S. J. Lindenbaum, Shielding Design for a 1000 Bev Proton Accelerator, PD-41 (September 29, 1961). Availability: \$19.75 (fs), \$9.25 (mf), CFSTI.

The shielding requirements of a 1000 Bev proton accelerator are discussed.

- 43S. A. J. Masley and A. D. Goedeke, Complete Dose Analysis of the November 12, 1960, Solar Cosmic Ray Event, N62-15220 (April-May 1962). Availability: NASA, Office of Scientific and Technical Information, ATTN: Acquisition and Dissemination Branch, Code AFSS-A, Washington, D. C.

The dose as a function of shield thickness from a particular solar flare is calculated.

- 44S. H. DeStaebler, Jr., Some Remarks on Forward Shielding-Mostly Muons, SLAC TN-62-66 (October 1962). Availability: Dr. H. DeStaebler, Jr., Stanford Linear Accelerator, Stanford, California.

For thick shields muons are a more serious radiation hazard than neutrons. Under many circumstances the main source of muons is direct μ pair production. Muons from the decay of pions produced via the statistical model or single pion photoproduction may be important at large angles.

We consider the effects of angular distribution and scattering on the muon radiation level.

We make rough applications to the radiation level outside of a 60 ft earth shield (at this thickness neutrons are negligible) and to the question of berm height (no particular height is suggested).

We use $2.0 \text{ MeV/g cm}^{-2}$ for the ionization loss in earth, $6.5 \mu\text{cm}^{-2}\text{-sec}$ as tolerance (0.75 mrem/hr), and electron beams of 40 Bev at $60 \mu\text{a}$ or 25 Bev at $100 \mu\text{a}$ stopping in iron targets.

Some of the muon problems have been discussed by Muray.

- 45S. J. Baarli, K. Goebel and A. Sullivan, An Experimental Study of the Penetration of 10 and 19.2 GeV Proton Radiation in Steel, DI/HP/15 (May 15, 1963). Availability: Health Physics, CERN, Geneva, Switzerland.

A 2m thick absorber made of 1 x 1.6 x 0.1 m steel plates was irradiated with a narrow beam (0.5 x 0.5 cm) of 10 and 19.2 GeV protons. Measurements were made of the radiation along the beam direction using C^{11} activation and ionization chambers. Particle flux distribution was also measured perpendicular to the beam direction at several depths in the absorber. The m-f-p and flux contours are given for both energies.

Similar measurements were made using C^{11} to estimate the flux contours in steel due to the scattered radiation from a 5.5 g/cm^2 Be target exposed to 10 and 19.2 GeV radiation.

- 46S. W. N. Hess, E. H. Canfield, and R. E. Lingenfelter, "Cosmic Ray Neutron Demography," J. Geophys. Res., 66(3), 665-77 (March 1961).

Calculations have been made to understand the life histories of neutrons made in the atmosphere of the earth. The sources of neutrons are discussed. The experimentally measured equilibrium energy spectrum is calculated by diffusion theory. The fates of the neutrons are presented, including the number and energies of neutrons leaking out of the atmosphere. The number of neutrons decaying in space near the earth is calculated to use as a source for particles in the radiation belt.

- 47S. S. P. Shen, Passage of High-Energy Particles in Matter: Nuclear Cascades Induced in Dense Media by 1- and 3-GeV Protons, BNL-8721 (1964). Availability: Brookhaven National Laboratory, Upton, N. Y.

A series of experiments designed to survey the main features of the nuclear cascade induced by monoenergetic protons in thick absorbers have been performed using 1- and 3-GeV protons on iron, 1- and 3-GeV protons on material resembling chondritic meteorites, and 1-GeV protons on Plexiglas ($C_5H_8O_2$). The F^{18} and Na^{24} activities induced in aluminum foils embedded at various depths in the absorbers were measured. These measurements, usable for detailed comparison with nuclear-cascade calculations, are then roughly translated into the fluxes of the fast-neutron component and of the high-energy component (nucleons and pions above 50 MeV) in the cascade. The main results are summarized in families of transition curves, the principal features of which in general depend smoothly on the incident energy, on the energy of the detected component, and on the absorber mass number. A few lateral-spread measurements are also given; in particular, the lateral spread of fast neutrons is, for given large depths, smaller in the 3-GeV-on-Fe cascade than in the 1-GeV-on-Fe cascade, as expected. Albedo of the high-energy component at the bombarded surface is practically nil for the 1-GeV cascades, and is 1 and 0.3 albedo particles per primary proton respectively for the 3-GeV-on-Fe and 3-GeV-on-chondrite cascades. Results of cosmic-ray and astrophysical interest are noted.

- 48S. R. H. Thomas (Editor), Report of the Shielding Conference Held at the Rutherford Laboratory on September 26th and 27th, 1962, NIRL/R/40 (June 1963). Availability: National Institute for Research in Nuclear Science, Rutherford High Energy Laboratory, Berkshire, ENGLAND.

No abstract needed.

- 49S. P. H. Fowler and D. H. Perkins, Cosmic Radiation and Solar Particles at Aircraft Altitudes - Background Note, SAAC/20 (September 25, 1962) Availability: Dr. P. H. Fowler, H. H. Wills Physics Laboratory, University of Bristol, ENGLAND.

The report describes the distribution and time dependence of Galactic Cosmic radiation and outlines the biological effectiveness of the radiation. Cascade effects are shown to be of no importance in terms of aircraft structure. It is logical to infer that sufficient weight of shielding to introduce problems of cascade effect would put up wingloadings to a level where an aircraft could not take off. The report goes on to show that while galactic cosmic radiation presents no worse hazard than is met in current subsonic jets, there is a need to consider the provision of a warning system for solar cosmic radiation (solar proton flares). It is shown that while flight up to about 70,000 ft is not likely to present serious problems, flights over this altitude will require special precautions.

- 50S. Trutz Foelsche, "Spectral Intensity Variations with Time in Specific Solar Flare Events and Radiation Doses," ASTM Spec. Tech. Publ. No. 363, 1-13 (1964).

Variations of the spectra of specific energetic flare particle events are considered, and an estimate of the doses in free space for different shielding thicknesses for the events of the highly active period May 1959 to November 1960 is given. The high energy part of the spectra ($E > 20$ MeV), because of minimum amounts of shielding being present and because of the relatively low intensities behind such shield, is mainly important for effects on man. With respect to effects on material and sensitive electronic devices, attention is given to low energy protons in the MeV range, which are observed since late 1960 to be present in appreciably higher intensity during proton events associated with large magnetic storms. Under the assumption that particles $E > 1$ Mev arriving in such large numbers as in the November 12, 1960, and in July 12, 1961, events, are a usual feature of solar events accompanied by large magnetic storms, fluxes between 4×10^{11} to 10^{12} protons per cm^2 are obtained for the 1 1/2 year period May 1959 to November 1960. These proton numbers and the doses are threshold doses for permanent or transient effects on the surface or in thin sheets of sensitive materials and devices. The intensities are in the same order of magnitude as the intensity of low energy protons in the maxima of the belts. For long-term excursions during solar activity years these low energy protons may have to be taken into account with respect to the selection of surface materials and protection of sensitive devices especially if the spacecraft approaches the sun more closely.

- 51S. Martin J. Berger and Stephen M. Seltzer, Multiple-Scattering Corrections for Proton Range Measurements, NAS-NRC-PUB-1133, p. 69-98 (1964). Availability: \$7.00 (NAS).

Three approximate methods are described that may be used to calculate differential and integral distributions of projected range, median ranges, and curves of ionization versus depth (Bragg curves) for protons traversing thick absorbers. One of the methods is based on the application of a multiple-scattering detour distribution obtained by Yang; the second method is due to Bichsel and Uehling; and the third makes use of random sampling. Two types of statistical fluctuations are taken into account: energy loss straggling in collisions with atomic electrons, and the "wiggleness" of the track (detours) due to multiple Coulomb scattering by atoms. All three methods were used to extract the values of the proton c.s.d.a. range, r , and of the mean excitation energy I_{adj} , of the medium from Bragg curves in lead and copper measured by Mather and Segre and by Zrelov and Stoletov. They give results for r and I_{adj} that are in good agreement with each other, but do not account entirely for shape of the measured Bragg curves.

- 52S. Stephen M. Seltzer and Martin J. Berger, Energy-Loss Straggling of Protons and Mesons: Tabulation of the Vavilov Distribution, NAS-NRC-PUB-1133, p. 187-203 (1964). Availability: \$7.00 (NAS).

This paper contains a tabulation of the Vavilov distribution which describes the energy-loss straggling of charged particles traversing a thin layer of matter. The distribution depends on the particle velocity and on a parameter, k , indicative of the ratio of the mean energy-loss over the pathlength considered to the largest energy-transfer possible in a single collision with an atomic electron. As $k \rightarrow 0$, the Vavilov distribution goes over into the Landau distribution; for $k \geq 10$ it becomes Gaussian. Intermediate values of k occur for protons and mesons of moderate velocity traversing very thin targets or for extremely fast particles in targets of moderate thickness.

- 53S. R. G. Alsmiller, Jr., J. E. Murphy, and J. Barish, Numerical Solutions of the One-Dimensional Nucleon-Meson Cascade Equations, ORNL-TM-951 (September 1964). Availability: Oak Ridge National Laboratory, Oak Ridge, Tennessee.

In shielding calculations for high-energy accelerators it is necessary to solve the nucleon-meson cascade equations numerically for very large distances. For the case of a 10-GeV proton beam and a set of quite special physical assumptions, an analytic solution has been obtained and compared with the numerical solution. The two solutions are shown to be in excellent agreement for thicknesses as large as 30 collision mean free paths ($\sim 2800 \text{ g/cm}^2$).

- 54S. W. E. Kinney, A Monte Carlo Calculation of Scattered Neutron Fluxes at an Air-Ground Interface Due to Point Isotropic Sources on the Interface, ORNL-3287 (July 1962). Availability: \$1.00, CFSTI.

Scattered neutron fluxes on the interface between SiO_2 ground and air due to 1- and 19-MeV point isotropic monoenergetic sources located on the interface have been calculated by the Monte Carlo method at distances out to 4×10^5 cm from the source. The validity of the method was established by comparing Monte Carlo results for an infinite air medium with moments method results. The two methods were found to yield fluxes that were in good agreement out to 8 source mean free paths for a 2-MeV source. At high source energies the treatment of inelastic scattering as isotropic elastic scattering over-estimated the high-energy flux and underestimated the low-energy flux, while allowing only P_1 anisotropic elastic scattering overestimated the flux near the source and underestimated it far from the source. Scattered neutron fluxes at the interface of black ground and air, which is a useful limiting case, were also calculated.

- 55S. R. G. Alsmiller, Jr., F. S. Alsmiller and J. E. Murphy, Nucleon-Meson Cascade Calculations: Transverse Shielding for a 45-GeV Electron Accelerator (Part I), ORNL-3289 (December 1962). Availability: \$2.25, CFSTI.

Using a straight-ahead approximation, a set of coupled integrodifferential transport equations which describe a nucleon-meson cascade is given. In order to carry out calculations the necessary physical information concerning high-energy interactions has been extracted from cosmic-ray data by introducing many ad hoc assumptions.

Calculations have been carried out for several cases which are of interest in the design of the shield for the proposed 45-GeV Stanford accelerator. Because of the very crude nature of the input data the results must be considered very approximate.

The equations and the IBM-7090 code which solves them numerically are not restricted to the Stanford problem, but may be used for other high-energy shielding calculations.

- 56S. R. G. Alsmiller, Jr., F. S. Alsmiller, and J. E. Murphy, Nucleon-Meson Cascade Calculations: Transverse Shielding for a 45-GeV Electron Accelerator (Part II), ORNL-3365 (February 1963). Availability: \$1.00, CFSTI.

In a previous report nucleon-meson cascade calculations were carried out for several cases of interest in the design of the transverse shield for the proposed 45-GeV linear electron accelerator at Stanford University. In this report results are given for several additional cases.

- 57S. R. G. Alsmiller, Jr. and J. E. Murphy, Nucleon-Meson Cascade Calculations: The Star Density Produced by a 24-GeV Proton Beam in Heavy Concrete, ORNL-3367 (January 1963). Availability: \$0.50, CFSTI.

The nuclear star density produced by a 24-GeV proton beam in a material having approximately the properties of heavy concrete has been calculated. A comparison has been made with experimental measurements made at CERN, but, since the quantity which could be calculated is not the same as that which was measured, no firm conclusions can be drawn.

- 58S. R. G. Alsmiller, Jr., and J. E. Murphy, Nucleon-Meson Cascade Calculations: Shielding Against an 800-MeV Proton Beam, ORNL-3406 (February 1963). Availability: \$0.50, CFSTI.

Nucleon-meson cascade calculations have been carried out and the dose as a function of depth has been obtained for an 800-MeV proton beam incident on a shield. The physical properties used for the shielding medium are only a rough approximation to the properties of any particular medium.

- 59S. R. G. Alsmiller, Jr., F. S. Alsmiller, and J. E. Murphy, Nucleon-Meson Cascade Calculations: Transverse Shielding for a 45-Gev Electron Accelerator (Part III), ORNL-3412 (March 1963). Availability: \$0.75, CFSTI.

In two previous reports nucleon-meson cascade calculations were carried out for several cases of interest in the design of the transverse shield for the proposed 45-Gev linear electron accelerator at Stanford University. In this report results are given for two additional cases.

- 60S. F. C. Maienschein and T. V. Blosser, The Depth-Dose Distribution Produced in a Spherical Water-Filled Phantom by the Interactions of a 160-MeV Proton Beam, ORNL-3457 (June 1963). Availability: \$0.75, CFSTI.

Measurements have been made of the total energy deposited at various points within a 42-cm-dia spherical water-filled lucite phantom by the secondary particles resulting from 160-MeV proton reactions with various targets. The proton source was the Harvard University Synchrocyclotron. Target materials were water, aluminum, carbon, copper and bismuth. Detectors were small lucite-walled ionization chambers filled with 97% A - 3% CO₂ or ethylene gas. Data were taken both with the lucite phantom on the beam axis and with the phantom offset approximately 54° - 43' from the beam axis. The proton beam energy determined from a part of these results, 160-162 MeV, is in good agreement with published values. The energy deposited by secondary particles was found to increase with Z, as expected. The depth-dose curves obtained have a steeply negative slope over the region near the surface of the phantom and a more gentle slope at greater depths. The magnitude of the dose in the region of the initial slope decreases with increasing target thickness. The dose in this region is presumably due to secondary protons. The magnitude of the dose at greater depths increases with increasing target thickness. At the greater depths the slope of the depth-dose curves, presumably controlled by secondary neutron interactions, is similar to that observed when the depth dose due to a Co⁶⁰ gamma-ray source was measured.

- 61S. Trutz Foelsche, Radiation Exposure in Supersonic Transports, NASA TN-D-1383 (August 1962). Availability: \$1.00 CFSTI.

Radiation exposure levels for flight personnel and passengers in supersonic transport operations at altitudes up to 75,000 feet (23 km) are estimated on the basis of recent data, and compared with the maximum permissible exposure levels for normal peacetime operations recommended in 1960 in the guides of the Federal Radiation Council.

- 62S. C. Johansson and M. Leimdorfer, A Monte Carlo Procedure for Calculating the Migration of Protons Taking Account only of Electromagnetic Interactions, FOA 4 RAPPORT A 4411-411 (January 1965). Availability: Forsvarets forskningsanstalt, Avdelning 4, Stockholm 80, Sweden.

The present report describes a method by which one can study the penetration and slowing-down of protons due to proton-atom interactions of non-nuclear type. A "continuous slowing-down" model has been applied which moves the protons down in energy between a set of predefined energy points. A sample result shows the expected energy distribution of 187 MeV protons after penetrating aluminum slabs of various thicknesses. The calculations are presently being checked at the cyclotron at Uppsala University.

638. J. B. Weddell, Primary and Secondary Nucleon Fluxes and Dose Rates by Straight-Ahead Approximation, SID-64-76 (January 1964). Availability: North American Aviation, Inc., Downey, California.

This report describes the method and some results of a calculation of the energy spectra and tissue dose rates beneath a slab shield, due to primary protons, secondary protons, and secondary neutrons. The rate of energy loss of protons is represented as the sum of two power-law terms. The production and penetration of secondary particles is treated by a generalized form of the straight-ahead or one-dimensional approximation of Rossi. An alternative and superior approach to the secondary neutron flux and dose rate is developed in which the neutron slowing-down length is analogous to the energy relaxation length of protons.

The computer program which embodies the calculation method is described, and its listing and location map are given in an appendix. This appendix is not included in externally distributed copies.

Results are presented in which galactic protons are incident on the earth's atmosphere and tissue is represented by water. The results agree well with those of manual calculations based on a different form of straight-ahead approximation.

In another appendix, it is shown that when the energy loss rate of protons in a homogeneous medium is the sum of two power-law terms in the energy, then the range-energy relationship can be expressed in terms of gamma functions and incomplete beta functions.

- 64S. R. A. Weagant, Nomogram for Heavy Charged Particle Shielding Calculations, STD 64-10 (January 15, 1964). Availability: North American Aviation, Inc., Downey, California.

The Proton Shielding Nomogram may be used to calculate primary particle doses and dose rates from protons, alphas, mesons, hyperons, and heavy ions. The principal application is anticipated to be the calculation of primary proton dose rates from the proton radiation found in space. This calculation is performed explicitly; the others are performed with the aid of simple conversion factors. Doses and dose rates are calculated for an isotropic particle flux incident upon a model shield composed of an infinitesimal element of water (or, approximately, tissue) located at the center of a spherical shell of water. The nomogram was constructed from results obtained from an approximate theory based upon empirical fits to range-energy and ionization loss data. The dose rates from the nomogram deviate by usually no more than 15 percent and never more than 20 percent from solutions based upon numerical integrations. In addition to the nomogram, a brief development of the dose equation, tables of equivalent shield thicknesses, conversion factors for different particle species, and sample calculations are included.

- 65S. Proceedings of the Symposium on the Protection Against Radiation Hazards in Space held in Gatlinburg, Tennessee, November 5-7, 1962, TID-7652, Vol. 1 and 2. Availability: \$7.00, OTS for both volumes.

No abstract needed.

- 66S. L. Beebe, J. Cumming, W. Moore, C. Swartz, Shielding Measurements (October 1, 1956). Availability: Not available to the public.

- 67S. E. L. Chupp, D. L. Dye, B. W. Mar, L. A. Oncley, and R. W. Williams, Analysis of Solar-Flare Hazard to Manned Space Systems, D2-11608 (Ad 606548) (1961) Availability: CFSTI.

An evaluation of the solar-flare proton radiation hazard is presented. By a detailed analysis of all available rocket, balloon, and riometer data for solar-flare proton events from February 1956 to September 1960 (Solar Cycle 19 maximum), an estimate is made of the total (time-integrated) proton flux ("size") and a power law differential spectrum is estimated for each event. An integral flare-event size-frequency distribution is then found which, with the assumption of randomness of occurrence of events, is a measure of the encounter probability for a solar-flare proton event greater than a given size.

Brief consideration of radiobiological effects of the nonuniform dose distributions resulting from flare proton spectra leads to the assignment of the absorbed dose at 4-centimeter depth in tissue as representative of the medically significant dose for flare events. Then, the 4-centimeter tissue slab depth dose (with no external shield) is calculated by an IBM code for each of 36 flares; the effect of a 5 g/cm² aluminum shield is also computed. From these dose values an integral dose-probability distribution is obtained for all observed solar-flare proton events.

The dose values obtained for all but the largest five solar-flare proton events are very small; all but the largest of the five event doses are probably sublethal--a result apparently at variance with some of the previous dose estimates due to different assumptions. Addition of small (up to 10 g/cm²) amounts of shielding will reduce the dose from four of the five largest events to tolerance levels without causing appreciable secondary buildup radiation.

A typical space vehicle design is analyzed for its solar-flare proton shielding effectiveness, and a factor of three to ten reduction in dose is found.

It is concluded that the probability of encountering a dangerous dose level in the course of a week's space flight is comparable to, or less than, the probability of a fatal accident in a week of flying in an operational military aircraft. Use of a solar-flare proton event prediction criterion will reduce the hazard by a factor of three for a short mission; the use of a small amount of extra shielding will reduce the dose encountered by a further factor of up to ten.

- 68S. G. E. Fichtel, D. E. Guss, H. H. Malitson, K. G. McCracken, K. W. Ogilvie, and W. R. Webber, Solar Proton Manual, X-611-62-122 (1962). Availability: NASA, Goddard Space Flight Center, Greenbelt, Maryland.

Solar particle outbursts are studied in an attempt to summarize the experimental knowledge in this field for the benefit of the spacecraft design engineer. A phenomenological description of solar particle events is presented and time histories and tabulated data are given for the major events. The anisotropy of high energy solar cosmic rays observed in several events is also treated.

- 69S. T. G. Barnes, E. M. Finkelman and A. L. Barazotti, "Radiation Shielding of Lunar Spacecraft," Lunar Exploration and Spacecraft Systems, Plenum Press (1962), pp. 52-71.

A description of the radiation environment to be encountered in space is presented. Based on available experimental data, a model of the spatial, spectral, and temporal variation of charged particles from the Van Allen Belts and cosmic radiation is established.

The attenuation of charged particles has been calculated using data on the range and relative energy loss as function of energy for protons and electrons in various materials. Calculations have been performed to determine the relative effectiveness of varying thicknesses of different shielding materials as a function of geometry of the shield. Shield weight penalties as a function of material and threshold energy for a representative hazard chamber are presented. Tissue dose rate variation with time for a typical three dimensional lunar trajectory is presented and compared to flight radially in the plane of the magnetic equator. Total integrated biological dose as a function of carbon shield thickness was calculated for four solar flare events, and for flight radially out through the inner belt. Considering the amounts of ablation material, structure, and equipment surrounding the crew in a reentry vehicle, it was found that the additional shielding required for traversal of the belts is small. It is shown that approximately 10 g/cm^2 of carbon shielding is sufficient to shield not only the inner belt protons, but would also provide adequate protection against solar flares of the magnitude that occurred in March and August of 1958. However, it was also found to be impossible to shield against solar flares of the highest known energy within the reasonable weight limits of a typical lunar mission. Since adequate shielding cannot be provided against these very intense solar proton events, the probability of encountering these and various lesser intensity flares is extremely important. Accordingly, the probability of encountering solar protons as a function of mission is presented. These encounter probabilities are considerably reduced if flares can be predicted. Continuing effort in this area indicates that degree of solar flare prediction is feasible.

- 70S. Lewis E. Wallner and Harold R. Kaufman, Radiation Shielding for Manned Space Flight, NASA TN D-681 (July 1961) Availability: \$1.25, CFSTI.

In order to assess the possible shielding weight penalties, a study was made of radiation hazards to which astronauts will be exposed on future journeys into space. Cosmic radiation, solar flares, the Earth's Van Allen belts, and nuclear radiation from a reactor were considered for both short and long travel times, such as would be of interest in lunar and Mars missions. Although accurate radiation knowledge is somewhat deficient in several areas, enough information is available to assess the order of magnitude of each radiation hazard.

For the long-term mission to Mars where the travel time may be 1 1/2 years or more, cosmic and solar-flare radiations may require biological-shield weights in the 100,000-pound class. These high values are the result of extrapolation of solar-flare spectra and involve considerable uncertainty. Increasing the radiation dose level several hundred percent above the present-day acceptable limits does not eliminate the need for heavy biological-shield weights. Shield needs for the nuclear reactor and the Van Allen belts are an order of magnitude less than this, except for slow traversal of the Earth's radiation belts.

Considerable weight saving can be had if a common shield mass is utilized against all the various radiation hazards. To cope with such heavy shield weights as would be required on a Mars mission, it is probable that space assembly or refueling will be necessary. For early space experiments beyond the Earth's magnetic field with the use of chemical-rocket propulsion, major solar flares probably constitute the prime radiation hazard. It is possible that a partial body shield that would afford adequate radiation protection for short exposure times can be designed with a weight penalty as low as 100 pounds per man.

- 71S. R. H. Thomas, Estimates of Particle Fluxes and Dose Rates in 200-Gev Machine Room, UCID-10135 (November 10, 1964). Availability: University of California, Lawrence Radiation Laboratory, Berkeley, California.

Estimates are made of the thermal neutron and fast particle fluxes inside the machine based on measurements at the AGS. From these flux estimates the dose-rates expected inside the machine-room are made and compared with Brookhaven data.

- 72S. R. H. Thomas, Strongly Interacting Particle Shielding, UCID-10134 (November 13, 1964). Availability: Lawrence Radiation Laboratory, Berkeley, California.

Approximate estimates of the main ring shielding were made some time ago (December 1963). Since that time, several design features have clarified and a great deal of information has become available which enables better estimates to be made.

- 73S. Andrew J. Beck and Edward L. Divita, "Evaluation of Space Radiation Doses Received Within a Typical Spacecraft," ARS Journal, 32, 1668-1676 (November 1962).

An analysis of radiation levels that may be expected from the natural radiation environment is presented for 1) primary solar flare protons and protons contained in the inner Van Allen belt; 2) secondary radiation such as neutrons from (p,xn) nuclear reactions, gamma rays from (p,x γ) nuclear reactions, and protons from (p, xp') nuclear reactions; and 3) electrons and electron-produced bremsstrahlung. The proton, neutron, and bremsstrahlung energy spectra and radiation doses are evaluated within aluminum spherical shells of various thicknesses for models of the proton fluxes from the May 10, 1959 and February 23, 1956 solar flares and protons contained in the inner Van Allen belt, as well as for models of the electron fluxes contained in the inner and outer Van Allen belts. Finally, these radiation quantities are evaluated within a typical spacecraft, considering its detailed material and equipment layout.

- 74S. William W. Wadman, Summary of Shielding Calculations Based on Texas A & M University 88-inch Cyclotron Specifications, UCID-2437 (December 14, 1964). Availability: Lawrence Radiation Laboratory, Berkeley, California.

Shielding calculations for the Texas A & M Cyclotron were based upon previous work by Moyer, Patterson, and Wallace for the Berkeley 88-Inch Cyclotron, and Moyer for the USNRDL 70-Inch Cyclotron. Experimentally determined values for the Berkeley 88-Inch Cyclotron shielding effectiveness were incorporated in these calculations.

- 75S. Roger Wallace, Palmer G. Steward, and Charles Sondhaus, Primary and Secondary Proton Dose Rates in Spheres and Slabs of Tissue, UCRL-10980 (Revised) (July 30, 1964). Availability: Dep. (mn); \$3.00 (cy), 2(mn), CFSTI.

A code has been developed for the depth-dose relation in spheres of tissue due to primary protons and to cascade, evaporation, and hydrogen elastically scattered secondary protons. Hydrogen elastically scattered protons are assumed to be emitted in the forward direction, as also, on the basis of Metropolis's calculations, are cascade protons. Evaporation protons are assumed to deposit their dose locally. It is shown that the dose rate at a depth d in a slab due to a normally incident parallel broad beam of protons is the same as the dose rate at the center of a sphere of radius d when an isotropic flux is incident upon the sphere.

The depth-dose results are checked by experiments using 730-MeV protons, and compared with Monte Carlo calculations performed at Oak Ridge for 400-MeV protons. The results show that the depth-dose pattern varies widely with proton energy and sphere size. For certain intermediate proton energies, the primary protons cause a peak dose rate at a predictable depth in the sphere. The secondary proton dose rate increases with increasing incident proton energy, sphere size, and depth. Protons of 730 MeV cause a secondary proton dose at the center of a 2.5-cm-radius sphere which is 14% of the total dose, 35% for a 10-cm radius, and 46% for a 25-cm radius.

- 76S. H. W. Patterson, W. N. Hess, B. J. Moyer and R. W. Wallace, "The Flux and Spectrum of Cosmic-Ray Produced Neutrons as a Function of Altitude," Health Physics, 2(1), 69-72 (Oct. 1959).

A series of measurements of neutron flux as a function of altitude has been made with the following neutron detectors: bismuth fission ionization chamber, proton-recoil proportional counter, and moderated and bare BF_3 proportional counters. In addition, data were also taken with a Simpson pile. Altitudes ranged from sea-level to 40,000 ft and latitudes from 28° to 49°N . Appropriate treatment of the data can be made to yield information about the neutron spectrum and the average neutron energy, and consequently about the dose rate.

- 77S. E. S. Matusevich and S. G. Tsypin, "Problems in the Radiation Protection of Human Beings in Cosmic Space," Soviet J. At. Energy (English Transl.), 15(6), 1287-93 (Dec. 1963).

A discussion is given of the sources and the biological effect of ionizing radiations in the cosmos. Estimates are given for the weight of shielding required by a space ship. It is shown that the weight of shielding required when the ship is passing through the radiation belts, and when solar flares occur, is several tons. The shielding from galactic cosmic radiation which is required when making possible, long interplanetary flights, is probably very extensive, and will weigh about ten tons.

- 78S. T. Foelsche, "Specific Solar Flare Events and Associated Radiation Doses," ASTM Spec. Tech. Publ. No. 363, 1-13 (1964).

Spectral variations of specific solar flare particle events are considered, and an estimate of the doses in free space for different shielding thicknesses for the events of the highly active period from May 1959 to November 1960 is given. The high-energy part of the spectra (E greater than 20 MeV), because of minimum amounts of shielding present and the relatively low intensities behind such shielding, is primarily important for its effects on man. With respect to effects on material and sensitive electronic devices, attention is given to low-energy protons in the Mev range, which have been observed since late 1960 to be present in appreciably higher intensity during proton events associated with large magnetic storms. Under the assumption that particles with $E > 1$ Mev arriving in such large numbers as in the November 12, 1960, and in July 12, 1961, events, are particles trapped in plasma clouds, and are a usual feature of solar events accompanied by large magnetic storms, fluxes between 4×10^{11} to 10^{12} protons per sq cm are obtained for the 1 1/2 year period between May 1959 and November 1960. These proton numbers and the doses are threshold doses for permanent or transient effects on the surface or in thin sheets of sensitive materials and devices. The intensities are of the same order of magnitude as the intensity of low-energy protons in the maxima of the belts. For long-term excursions during solar activity years these low-energy protons may have to be taken into account with respect to the selection of materials and protection of sensitive devices, especially if the spacecraft approaches the sun more closely.

- 79S. G. Bathow, E. Freytag and K. Tesch, "Shielding Measurements on 4.8-GeV Bremsstrahlung," Nucl. Instr. Methods, 33(2), 261-267 (March 1965).

Bremsstrahlung produced by 4.8-GeV electrons impinges upon a quantameter; the emerging radiations and their attenuation in heavy concrete are measured. The following instruments are used: tissue-equivalent ionization chamber, argon-filled ionization chamber (Jordan chamber), neutron dosimeter and several activation foils for measuring the neutron flux. Results are given for the neutron flux and dose rates of some radiation components behind concrete shielding up to 160 cm and at angles from 0° to 125° , for the attenuation coefficients of the radiation components, and for the number of giant-resonance neutrons produced per eq. γ quantum.

- 80S. M. J. Berger and S. M. Seltzer, Results of Some Recent Transport Calculations for Electrons and Bremsstrahlung, NBS Report 8509 (December 1964). Availability: National Bureau of Std., Washington, D. C.

Illustrative results are given for three types of problems: (1) the transmission of electrons through thin and thick foils, with emphasis on the effect of energy loss straggling; (2) the energy dissipation by electrons in a semi-infinite water phantom, for an incident broad beam (depth dose distribution) and for an incident pencil beam (distribution as function of two spatial variables); (3) the production of bremsstrahlung in thick targets. The data presented for the first two problems are entirely theoretical and result from a Monte Carlo calculation. Similar calculations for the third problem are compared with recent experiments.

- 81S. W. Cranford, R. F. Falkenbury, and R. A. Miller, A Space Trajectory Radiation Exposure Procedure for Cislunar Missions, NARF-62-11T (FZK-9-178) (July 31, 1962). Availability: \$8.60 (fs), CFSTI.

The Space Trajectory Radiation Exposure Procedure (STREP) is designed to compute the time-integrated spectra for any specified trajectory in cislunar space for any combination of the several components of space radiations. These components include Van Allen protons and electrons; solar-flare protons, electrons, heavy particles, and gamma radiation; cosmic protons and heavy particles; albedo neutrons, and aurora borealis gamma radiation. The program will also calculate the accumulated dose behind a thin vehicle skin at any time after the start of the mission. The technique of interpolation for intermediate points along the prescribed space trajectory is described in detail. The method of representation of the space radiation data as input for the calculation of the dose and time-integrated spectra is discussed.

- 82S. Martin J. Berger and Stephen M. Seltzer, Energy Spectra and Angular Distributions of Electrons Transmitted through Sapphire (Al_2O_3) Foils, NASA SP-3008 (1964). Availability: NASA, Washington, D. C.

Monte Carlo results are presented, in the form of 72 tables, pertaining to the transmission of electrons incident with energies of 1, 2, 2.954, 4, 5.907 and 8 MeV on sapphire foils with thicknesses of 0.1, 0.2 and 0.3 g/cm². Two types of beam geometry are treated for all source energies: (a) perpendicular incidence; (b) beams with an initial cosine-law angular distribution (corresponding to an isotropic electron flux). For a source energy of 2 MeV, various incident beam obliquities are also treated, ranging from grazing to perpendicular incidence. The physical factors taken into account include the energy losses due to collisions with atomic electrons (mean value and fluctuations), the mean energy loss due to bremsstrahlung, and the angular deflections and path detours due to multiple Coulomb scattering by atoms.

- 83S. Microwave Laboratory, Stanford University, Shielding Plan for the Stanford Linear Accelerator, NP-1443 (February 1950). Availability: Microwave Laboratory, Stanford University, Palo Alto, California.

The projected production of billion-volt electrons introduces some new shielding problems. For guidance in design, the following attempt has been made to estimate the amount of shielding required by the various parts of the accelerator and associated equipment. The shielding actually used must be in any case checked by detailed and continuing radiation surveys. During construction such surveys will indicate when it is safe to raise the voltage or beam current.

Theoretical predictions are also useful in showing the types of radiation to be expected and the types of monitoring to be used.

The estimates made are not intended to represent the best calculations that could be made with the most recent information, but merely to give a reasonably reliable estimate based upon such information as was readily available at the time.

- 84S. J. E. Turner, C. D. Zerby, R. L. Woodyard, H. A. Wright, W. E. Kinney, W. S. Snyder and J. Neufeld, "Calculation of Radiation Dose from Protons to 400 MeV," Health Physics, 10(11), 783-808 (November 1964).

The Monte Carlo technique has been used to obtain estimates of dose and dose equivalent in a homogeneous tissue slab irradiated by a broad beam of normally incident monoenergetic protons and also for an isotropic flux of protons incident on a homogeneous parallelepiped of tissue. Incident proton energies as high as 400 MeV are considered. The dose is essentially uniform above 200 MeV, where average primary proton ranges become large compared with the mean track lengths of primary protons in the target. At all proton energies the ratio of rem and rad doses is generally about 1.4 if rem dose estimates are based on values of RBE in current use for long-term occupational exposure to ionizing radiation. The contributions to dose from various ranges of LET values which arise in the calculation are presented and discussed. The nuclear interactions considered are cascade and evaporation phenomena. The effect of the presence of pions is assumed to be negligible at incident proton energies not exceeding 400 MeV. An analysis of nuclear interactions is made from the standpoint of dose assessment. From the results of the detailed Monte Carlo calculations a simplified model is derived which permits a rapid and accurate estimation of proton dose. A method of handling RBE in a flexible manner is given also.

- 85S. A. Citron, L. Hoffman and C. Passow, "Investigation of the Nuclear Cascade in Shielding Materials," Nucl. Instr. Methods, 14(1), 97-100 (November 1961).

The build-up of the nuclear cascade and its subsequent attenuation has been measured in two types of concrete and earth using as primary radiation protons from the CERN-PS. From a narrow and a wide beam experiment we find the following lower limits for characteristics of the cascade: (1) there is a region of a full width of 550 g/cm^{-2} in which the intensity increases by a factor of 3, and drops down again to the initial value. (2) this is followed by a nearly exponential decrease of the intensity of the radiation with an attenuation length of $145 \pm 10 \text{ g/cm}^{-2}$.

- 86S. F. M. Byrne, M. A. Ellison, and J. H. Reid, "A Survey of Solar Flare Phenomena," Space Sci. Rev., 3(3), 319-341 (Oct. 1964).

A review of the known information concerning solar flare phenomena is given.

- 87S. T. A. Chubb and H. W. Smathers, Jr., Preliminary Report on the NRL 1963 Radiation Dosimeter Experiment Flown in Satellite 1963 - 21D, NRL Memorandum Report 1463 (October 11, 1963). Availability: Dep. (mn); \$2.00 (cy), 1(mn), CFSTI.

This document consists of an initial analysis of results of a radiation dosimeter experiment flown in the satellite 1963 - 21D. This experiment effectively measured the day-by-day accumulated Roentgen dose occurring inside the satellite housing. The initial satellite orbit was characterized by a very low apogee so that the orbit apogee decreased relatively rapidly with time. As a result the dosimeter experiment provided a study of daily radiation dose versus height. The dose was found to be produced almost entirely by trapped fission electrons from the STARFISH explosion. The experiment should eventually provide a quantitative measure of the intensity of STARFISH electrons in the lower fringe region of the artificial belt.

The present analysis of the Roentgen dose rates remains incomplete because of the unavailability at the present time of accurate daily orbits for the satellite. It is believed that once accurate orbit data are made available, the quantitative study of STARFISH intensity distribution may very possibly be important in determining the geophysical factors which control the lifetime of the belt.

- 88S. E. Bruninx, High-Energy Nuclear Reaction Cross-Sections, CERN-61-1 (January 16, 1961). Availability: Dep. (mc).

In this compilation are presented formation cross-sections for nuclides formed in nuclear reactions above 50 MeV. Many of these cross-section data are based on sometimes widely different values of the monitor reaction $^{27}\text{Al}(p,3p\text{n})^{24}\text{Na}$.

Therefore a "best" selection has been made from available data in the literature for this reaction. Whenever the value of the monitor reaction was outside the selected value (including error), the cross-section values were recalculated on the basis of the best value. The old value used originally by the authors is also mentioned.

Experimental errors are included in almost every case.

The cross-sections given in this volume are for target elements in the region Beryllium-Copper. No claim for completeness is made. Values originally present in the literature as graphs are not yet included. The target elements are classified according to their Z value, the nature of the bombarding particle (neutron, proton, deuteron, etc.) and the energy of the bombarding particle (from 50 MeV upwards).

- 89S. W. T. Roberts, Space Radiations: A Compilation and Discussion, NASA TM X-53018 (March 5, 1964). Availability: NASA, Marshall Space Flight Center, Huntsville, Alabama.

The natural radiations encountered during a space mission will fall into one of five categories. There will be Van Allen belts, galactic cosmic radiations, solar winds, solar flares, and photon radiations. Each type of radiation is examined from the point of view of the Apollo program and the associated lunar logistics vehicle, but with some comments pointing to extended missions in space, to determine the importance which should be assigned to each class.

- 90S. Richard H. Levy, "Radiation Shielding of Space Vehicles by Means of Superconducting Coils," ARS Journal, 31, 1568-70 (1961).

The general problem of shielding the occupants of manned space vehicles from various radiations likely to be encountered in space flight is discussed, and various published papers on the subject are briefly reviewed. The review indicates the importance of the problem and the interest that would attach to a radical solution. One possibility is shielding by the permanent magnetic field of a superconducting coil. A detailed analysis is made of the shielding that could be provided by such a coil and a preliminary estimate of the weight of such a device is made paying particular attention to the weight of the structure required to support the coil. A comparison is made of the weights calculated in this way with the weight of the spherical H_2O shield which would give comparable protection.

- 91S. R. T. Frost, Geomagnetic Protection from Solar Proton Events, R63SD101 (December 1963). Availability: General Electric, Missile and Space Division, King of Prussia, Pennsylvania.

Information on solar proton events and geomagnetic theory is reviewed. An upper limit for the omnidirectional flux received at a point within a dipole field in terms of the directions allowed by the Stoermer cone, and using the Webber-Freiser exponential rigidity spectra. It is found that, for the latitudes at which exposure to solar protons begins to become appreciable (50 to 60 degrees, depending upon the spectrum of the event), the further restriction of the allowed directions by the penumbra is unimportant. It is argued that shadow effect will cause a large reduction in the actual dose from the upper limit derived for a height of 85 nautical miles, but that the actual dose will approach the upper limit for a height of 400 nautical miles for isotropic events. Orbit averages for the geomagnetic protection factor are derived for circular orbits of various inclinations. Discussions are given of the limitation of the earth centered dipole model used for the orbit average and the effect of a ring current.

- 92S. A. J. Beck, E. Divita and S. L. Russak, "Evaluation of Space Radiation Safety Procedures in the Design and Operation of some Early Manned Lunar Vehicles," Proceedings of the Sixth Symposium on Ballistic Missile and Aerospace Technology, 3, 365-421 (1961).

This paper presents some of the results of investigations undertaken to determine the degree of radiation safety resulting from different lunar spacecraft design and mission operations. Included in the latter are the shaping of the trajectory to minimize time spent in the Van Allen Belt and the scheduling of launchings during periods of low solar activity. In the evaluation, a number of lunar vehicle preliminary configurations were analyzed. This procedure represented a departure from earlier work, which considered only regularly shaped bodies made up of one elementary material. In this more recent study, we used actual compound materials in the proper weight and stratified position applicable to each configuration.

Also included is an examination of a separate radiation "storm cellar" as well as the radiation protection afforded by additional "spot" shielding within the cabin. Models of the radiation environments developed for the investigation are also presented. It has been determined that a very significant factor in the crew radiation exposure levels is the attenuation afforded by the materials of the basic spacecraft—and that this varies considerably among lunar spacecraft designs.

Selection of trajectory and launch periods offers up to an order of magnitude decrease in dosages, but at the expense of decreased operability. With the environmental models employed, it appeared that such operational limitations may not be necessary, but that for, up to fourteen-day missions, acceptable radiation dose limits may be achieved through vehicle design and the use of small masses of critically positioned shielding.

- 93S. Wilmot N. Hess, H. W. Patterson, Roger Wallace and Edward L. Chupp, "Cosmic-Ray Neutron Energy Spectrum," Phys. Rev., 116(2), 445-457 (October 15, 1959).

The cosmic-ray neutron energy spectrum in the equilibrium region of the atmosphere has been measured with several different calibrated detectors from thermal energies to about 1 BeV at 44° north magnetic latitude and up to 40,000 feet. By combination of the data from these measurements with those from other experiments, a complete differential energy spectrum is obtained which shows the characteristic maximum near thermal energies and a roughly $1/E$ variation up to about 100 kev. The presence of a second maximum in the spectrum near 1 Mev is attributed to the evaporation neutrons from stars, and above this energy up to 800 MeV the spectrum falls off as $E^{1.4}$.

- 94S. David L. Dye and Maurice Wilkinson, "Radiation Hazards in Space," Science, 147, 19-25 (January 1965).

Calculated values of the total primary proton and secondary particle dose absorbed at various points in the body of an astronaut within a spherical shell aluminum shield are reported. The incident particles were taken to be solar flux protons with a typical exponential rigidity spectrum ($P_0 = 100$ MV) and trapped protons from the inner Van Allen belt (Heckman and Armstrong spectrum). The statistical nature of the hazard from solar flare protons is emphasized, with graphs giving the probability per week of certain specified doses at 5 different body points, as functions of shield thickness. (ORSIC Abstract)

- 95S. S. J. Lindenbaum, "Shielding of High-Energy Accelerators," Annual Rev. Nucl. Sci. Reprint, 11, 213-258 (1961).

A general review of high energy accelerator shielding is given.

- 96S. Richard Wilson, A Revision of Shielding Calculations, CEA-73 (May 12, 1959). Availability: Cambridge Electron Accelerator, 42 Oxford Street, Harvard University, Cambridge 38, Massachusetts.

The shield calculations which were used in determining the shielding requirements of the Cambridge Electron Accelerator are described.

- 97S. K. More, O. L. Tiffany, and K. Wainio, "Cosmic Ray Shower Production in Manned Space Vehicles," Medical and Biological Problems of Space Flights, Academic Press (1963), pp. 201-224.

Manned aerospace vehicles operating in the vicinity of the earth or on lunar or planetary missions will be subject to cosmic, solar flare, Van Allen, and solar electromagnetic radiation. The size of these spacecraft and the duration of the mission may depend largely on the radiation dose the astronaut will receive. This paper describes the progress of a program for calculating the ionizing radiation in aerospace vehicles.

Several calculations have been completed for the secondary particle fluxes of neutrons, protons, and pi-mesons produced in cosmic-ray showers by high-energy cosmic protons in aerospace vehicles. To determine the possible methods of shielding the astronauts from radiation, these calculations have been carried out in three-dimensions for aerospace vehicles of varying thicknesses.

- 98S. C. M. Fisher, Notes on the Nuclear Cascade in Shielding Materials (October 1962). Availability: Rutherford High Energy Laboratory, Harwell, Didcot, Berkshire, England)

Using a special form of the production kernels analytic solution to the nucleon-meson cascade equations is obtained.